

THE NEED FOR A CONSISTENT WILDFIRE RISK TERMINOLOGY

Andreas Bachmann, Research Assistant & Britta Allgöwer, Research Associate
 Spatial Data Handling Division, Department of Geography, University of Zurich
 Winterthurerstr. 190, CH-8057 Zurich
 Phone: +41 1 635 51 54; Fax: +41 1 635 68 48
 Email: bachmann@geo.unizh.ch; britta@geo.unizh.ch

ABSTRACT

Reviewing wildfire literature shows considerable confusion on the use of risk related terms. The terms ‘danger’, ‘hazard’ and ‘risk’ are used freely and reciprocally expressing different notions in varying contexts. In this paper, these terms are critically reviewed and discussed. Subsequently, a set of consistent definitions is presented that is based on the concepts of technical risk engineering. It represents the conceptual base for quantitative risk analysis of the hazard wildfire considering spatio-temporal aspects explicitly. Based on that, a proposition to structure the main research topics (wildfire occurrence, behavior and effects) is presented.

Keywords: Wildfire Risk, Risk Terminology, Quantitative Risk Analysis, Geographical Information Systems (GIS)

INTRODUCTION

When looking through wildfire risk related literature one notices a great confusion on the proper use of terminology and, due to that, the absence of a comprising methodology. Further, models and computer simulations shut up like mushrooms; verification procedures, on the other side, are a difficult task. All this leads to the fact that comparison of the various investigations done in this field may be impossible or at least debatable. Hence, results may not be combinable and thus of no use for the improvement of wildfire management. Moreover, the somewhat inconsiderate use of the various terms ‘danger,’ ‘hazard,’ and ‘risk’ may result in misunderstandings that can have fatal consequences. Both, managers and researchers depend on comprehensive, reliable communication facilities. Much of the success of any management organization or process depends on the profound knowledge of the boundary conditions and predefined rules.

Some reasons for the lack of an overall approach to wildfire risk may result from the following facts:

- The term ‘risk’ is part of ‘everyday life’ where, depending on the context, a wide range of notions is assigned to it.
- Terminology is always to some extent a ‘linguistic’ and / or ‘cultural’ issue. Every language has its own words and meanings, e.g. the terms ‘hazard’ and ‘danger’ are the same word in German (i.e. ‘Gefahr’).
- The phenomenon ‘fire’ has as many aspects as people who are dealing with it: Fire managers and fighters, environmentalists, foresters, house and land owners, scientists, land planning organizations, etc. Based on their primary interests, each of these ‘communities’ has different notions of the term ‘wildfire risk.’

Objectives

The objective of this paper is to present a coherent wildfire risk terminology that is based on the experiences and achievements in technical risk engineering. We consider the application of this sound methodology and terminology appropriate to carry out quantitative risk analysis in the context of wildfire management.

A further objective is to show what part various topics of wildfire research play in the context of wildfire risk analysis. We believe that this will open up new insights to the phenomenon wildfire as it reveals relationships between factors, which are not obvious at first sight.

Finally, we recognize that a terminology is only then a useful terminology when it is accepted and applied by a majority of the involved people. We do not want to impose a new way of thinking, but we would like to animate a discussion that will help to establish a consistent wildfire risk terminology and methodology.

RISK RELATED TERMS

A short note on definitions

Definitions are constructed and valid only within a given scope (Seiffert 1997). They combine words with notions of, sometimes, complex phenomena in a unique way. Definitions are essential for reliable communication between involved people working on the same topic. They are used as ‘abbreviations’ for complex and difficult to explain matters. Definitions are never true or false, but useful or not useful within the scope they are applied.

Scope

The scope of the anticipated terminology is the application of technical risk engineering (i.e. quantitative risk analysis) in the context of wildfire management and research, considering spatio-temporal components explicitly.

In the following, some of the known definitions for ‘danger,’ ‘hazard,’ and ‘risk’ are discussed. In a next step, we will then propose our ‘own’ definitions that are tailored for the use within the mentioned scope.

Danger

Fire bound definitions of the term ‘danger’ tend to be vague; they reveal the difficulties to explain a phenomenon that is based on human perception mainly. Wildfires as a natural process are neither ‘bad’ nor ‘good’ – only when human optics come into play they are valued. Hence, some definitions recapitulate the components (physical preconditions and triggering factors [ignition sources]) that lead to an (undesired) event, some even include management activities into the definitions or refer to indices that express ‘fire danger.’ However, none of these definitions really tries to characterize the ‘phenomenon danger.’ Consulting a common dictionary, Webster’s College Dictionary (1992), a more abstract but more appropriate approach can be found, that describes danger as a set of ‘menacing circumstances’: “(1) liability or exposure to harm or injury; risk; peril. (2) an instance or cause of peril; menace. (...) Danger is the general word for liability to injury or harm, either near at hand and certain, or remote and doubtful. (...)”

In the following, two wildfire standard glossaries are cited. One was published by the ‘Food and Agricultural Organization of the United Nations’ (further re-

ferred to as FAO 1986) and the other was edited by the ‘Canadian Committee on Forest Fire Management’ (Poulin et al. 1987; further referred to as CCFFM 1987).

FAO (1986) defines fire danger as follows: “*Fire Danger: The resultant, often expressed as an index, of both constant and variable factors affecting the inception, spread, and difficulty of control of fires and the damage they cause.*” CCFFM (1987) states: “A general term used to express an assessment of both fixed and variable factors of the fire environment that determines the ease of ignition, rate of spread, difficulty of control, and fire impact.” Both definitions use the term danger to describe the set of preconditions that influence wildfires. However, in order to distinguish the contribution of each ‘factor’ it would be more appropriate not to mix them but to consider them separately. E.g., the ease of ignition is relevant for the probability of occurrence while difficulty of control is related to the outcome. As said before, these definitions do not explain the term danger but summarize what may influence and describe fires; vaguely the possibility of an event taking place is expressed as well. The same is true for the ‘Glossary of Forestry Terms’ from the Ministry of Forests (Province of British Columbia, Canada; further referred to as MOF 1997): “*Fire danger: an assessment of both fixed and variable factors of the fire environment, which determine the ease of ignition, rate of spread, difficulty of control, and the fire impact.*”

Hazard

Although often used as a synonym for danger, definitions of the term ‘hazard’ add a more precise, more ‘materialized’ notion by identifying ‘hazard objects.’ Eventually the relation to possible (human) harm is established as well. The following first definition in Webster’s College Dictionary (1992) comes close to the intention of ‘materializing’ danger: “(1) something causing danger, peril, risk, or difficulty (...) (2) the absence or lack of predictability; chance; uncertainty (...) (8) to take or run the risk of a misfortune, penalty etc.” Both, the FAO and the CCFFM glossaries give very narrow definitions where hazard is mainly related to the fuel complex and its properties. FAO (1986): “(1) (North America) A fuel complex, defined by volume, type condition, arrangement, and location, that determines the degree both of ease of ignition and of fire suppression difficulty. (2) (non-US English speaking world) A measure of that part of the fire danger contributed by fuels available for burning. Note: is

worked out from their relative amount, type, and condition, particularly their moisture content." Both variants define hazard as some sort of measure for a specific aspect of fire behavior related to fuels properties ('ease of ignition ... fire suppression difficulty' and 'fire danger'). The CCFFM glossary (1987) restricts the definition even more. It concentrates on the description of 'endogenous' fuel properties and excludes the influence of 'exogenous' properties like fuel moisture and / or suppression activities explicitly: "A general term to describe the potential fire behavior, without regard to the state of weather-influenced fuel moisture content and / or resistance to fireguard construction for a given fuel type. This may be expressed in either the absolute (e.g. 'cured grass is a fire hazard') or comparative (e.g. 'clear cut logging slash is a greater fire hazard than a deciduous cover type') sense. Such an assessment is based on physical fuel characteristics (e.g. fuel arrangement, fuel load, condition of herbaceous vegetation, presence of ladder fuels)." MOF (1997) defines fire hazard also in function of the fuel properties: "Fire hazard: the potential fire behavior for a fuel type, regardless of the fuel type's weather-influenced fuel moisture content or its resistance to fireguard construction. Assessment is based on physical fuel characteristics, such as fuel arrangement, fuel load, condition of herbaceous vegetation, and presence of elevated fuels."

In the domain of technical risk engineering, hazard is explained by a more general concept. Allen (1992, p. 9) defines hazard as follows: "Hazard: a physical situation with a potential for human injury, damage to property, damage to the environment or some combination of these." A hazard is not only the precondition for a specific process, as it is seen by the FAO, CCFFM and MOF glossaries, but it is the process itself. This definition has the advantage that it is applicable to any process that can lead to damage. Hence, according to this definition, *wildfire* is the hazard, like e.g. a mudslide or an avalanche.

Risk

The term 'risk' is used by very different communities and in various situations. Accordingly, a very wide range of notions is assigned to it. Nevertheless, risk seems to be alleged to two meaning complexes: loss, harm and injury on one side and chance and probability on the other side. Most definitions show difficulties though to clearly express this duality or just include one part into their explanations.

Taken as a whole, the set of definitions given by Webster's College Dictionary (1992) comes close to the two components of risk: "(1) *exposure to the chance of injury or loss; a hazard or dangerous chance.* (2) *Insurance: (...) b. the degree of probability of such loss, c. the amount that the insurance company may lose (...).*"

The following definitions presented by FAO and CCFFM are examples for explanations that look at one part of risk only. According to FAO (1986) risk is: "(1) *The chance of fire starting, as affected by the nature and incidence of causative agencies; an element of the fire danger in any area.* (2) *Any causative agency.*" The FAO definitions do not include the notion of damage but extend the term risk with 'causative agency.' Risk is in that sense not only an abstract descriptive property but it becomes a special 'type of action.' The same is true for the definition given by CCFFM (1987): "The probability or chance of a fire starting determined by the presence and activities of causative agents (i.e. potential number of ignition sources)." Both definitions represent a twofold cut-back of the term risk: they neglect the outcome (i.e. damage) as well as the preconditions and concentrate on the triggering factors of a fire (ignition sources) only.

MOF (1997) comes closest to the dual approach towards risk: "Risk: the probability of an undesirable event occurring within a specified period of time. With regard to insect populations, risk involves components to evaluate the likelihood of an outbreak, the likelihood of trees being attacked (susceptibility) or the likelihood of trees being damaged (vulnerability). In fire prevention, risk involves those things or events that cause fires to start (including the physical igniting agents and people)." However, when defining 'fire risk', the same glossary restricts the definition again to the aspect of occurrence probability and just cites the CCFFM glossary: "Fire risk: the probability or chance of fire starting determined by the presence and activities of causative agents."

In wildfire oriented literature only very few examples can be found that take both aspects of risk – probability and outcome – into account. Whereas Hall (1992), coming from structure fire science, refers to fire risk as being the product of probability and damage: "A measure of fire risk has two parties: (1) a measure of the expected severity (e.g., how many deaths, injuries, dollars or damage per fire) for all fires or for a particular type of fire, and (2) a measure of the probabil-

ity of occurrence of all fires or of that particular type of fire. In general, a fire risk measure will be a product of an expected severity term and a probability term or a sum of such products.” Unfortunately, this definition seems to have lacked the necessary support and / or diffusion in the wildfire research community.

In the area of technical risk engineering, we find the same rationale for the term risk (e.g. Jones 1992, Gheorghe and Nicolet-Monnier 1996, Merz et al. 1995). In the most general case, risk comprises likelihood and outcome (often referred to as damage or damage potential) and for quantitative risk analysis it is the product of both (Jones 1992).

Conclusion

For our work, we would like to define the previously discussed terms as follows:

Danger: *Danger is an abstract concept of human perception. Danger per se does not exist. It is defined by subjective human and societal perception and assessment of factors (of the physical and non-physical environment) that are considered harmful.*

Hazard: *A hazard is a process leading to undesirable outcomes.*

Risk: *Risk comprises the probability of an undesired event and the outcome of it. An undesired event is a realization of a hazard.*

For our work, we will neither use nor define the terms ‘danger’ and ‘fire danger’ anymore, while the term hazard will be used as an equivalent (‘synonym’) for the process itself (i.e. wildfire). Further, what is usually thought of as hazard or danger should be looked at as either a precondition (or a set of preconditions) of a fire (e.g. fuel properties) or as a triggering factor (i.e. ignition cause). Both elements are essential for a fire, but only a part of the ‘puzzle.’ In the anticipated GIS-based framework for quantitative wildfire risk analysis (see outlook), however, these elements can be positioned and assessed according to their contribution to fire risk.

Consequently, we will speak of risk (i.e. wildfire risk) alone and more specifically of quantitative risk as this allows the embedding of it in a risk management process, where risk analysis and also risk assessment are important steps (Bärtsch 1998). Moreover, we use the value-free term ‘outcome,’ as the effects of a wildfire don’t necessarily have to be negative.

QUANTITATIVE WILDFIRE RISK

For a quantitative analysis, it is necessary to operationalize the term risk, i.e. to describe the mathematical relationships between probability and outcome and to define indicators that can be used to measure their value. Generally, risk r is defined as the product of the probability p and the expected outcome d (Kumamoto et al. 1996, Jones 1992, Merz et al. 1995):

$$r = p \cdot d \quad (1)$$

p is a probability according to the axioms of Kolmogorov (1933) and is defined for a given time period, e.g. the occurrence probability of a wildfire in the next year is 0.8. Kolmogorov’s axioms don’t prescribe how probabilities are determined but define properties and calculation rules that have to be satisfied. This means that, e.g. a method resulting in an index of fuel moisture with an arbitrary scale can be transformed into an ignition probability with any appropriate function. d is a measure or description for the expected outcome, e.g. ‘2200 hectares of highly productive timber stands burned down’ or ‘increased biological diversity after disturbance in fire-prone ecosystems.’

Risk deals with future events, which cannot be predicted in a deterministic way. If place and time, all preconditions and the cause of a wildfire were known in advance, no risk analysis would have to be carried out. Therefore, as it is not possible to predict a ‘future event’ (due to the complexity of the process and the unknown input parameters), scenarios have to be constructed. Scenarios represent possible realizations of a hazard (i.e. wildfire). They define all relevant preconditions and causes of an event and thus enable the quantitative determination of risk.

There exist two perspectives of risk: the subjective and the collective. The first describes the perspective of a single exposed object, the so-called *risk acceptor*, which might be affected by many scenarios of presumably different types of hazards. The latter describes the perspective of a scenario, i.e. the *risk donor*, which might affect many risk acceptors. The two perspectives are primarily important for the risk assessment. E.g., the collective risk might be accepted, but on the individual risk level, it has to be rejected because either the damage or probability of one object is too high. This case can occur when individual outcomes and / or probabilities are unequally distributed.

Two specific points have to be considered in great detail when applying risk analysis methods to the envi-

ronmental hazard wildfire. Most technical hazards are fixed in space (e.g. the location of a power plant is given by spatial co-ordinates) or limited to some well defined locations (e.g. roads). This is clearly not the case with wildfires which in principle, can start at any point that is covered by combustible vegetation. The other crucial point is the selection of relevant impact indicators for various types of affected objects, e.g. power plant vs. endangered species habitat. In the opinion of Merz et al. (1995), damages should whenever possible be quantified, in order to enable their discussion and assessment. Considering this aspects we define:

Wildfire Risk: The probability of a wildfire to occur at a specified location and under given circumstances and its expected outcome as defined by the impacts on the affected objects.

Let us apply this definition in a hypothetical example (Figure 1): Within a given study area, there exist a certain number of objects O_i and some number of scenarios S_j .

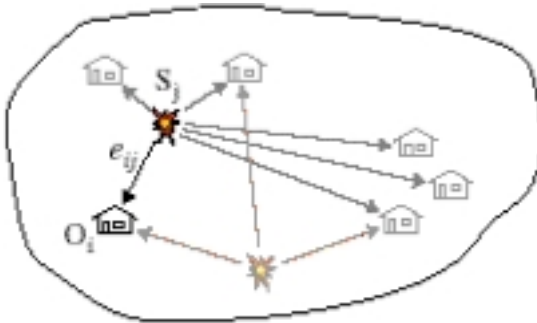


Figure 1. Relationships between Scenarios and Objects.

For every relation between a scenario S_j and an object O_i the individual probability of impact e_{ij} and the individual expected impact d_{ij} at the object is calculated.

The risk of a given scenario, i.e. the collective wildfire risk, is then:

$$r_j = p_j \cdot \sum_{i=1}^n e_{ij} \cdot d_{ij} \quad (2)$$

Figure 2 depicts a graphical representation of these fundamental relations. The probability p_j is the probability that a fire will start at a given location. The outcome of the scenario is a weighted sum of the impacts of all objects. The weighting is done with the impact probability, that is the probability that an object is reached and affected by a fire. The impact probability is determined by the fire spreading. Once, the

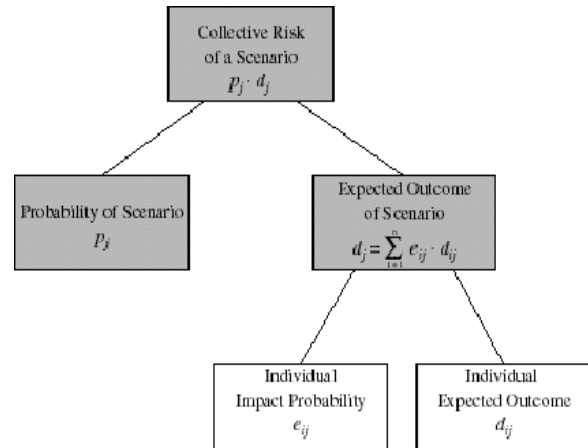


Figure 2. Collective Risk of a Scenario.

resulting fire perimeter of a given scenario is known, an individual impact probability of 1 will be assigned to all objects within that perimeter. Objects lying outside the perimeter will then have an individual impact probability of 0 and thus won't contribute to the sum of impacts.

For a comprising risk analysis, usually several scenarios have to be constructed in order to consider all relevant cases. The risk for the whole area is then the sum of the risk of each scenario.

STRUCTURING WILDFIRE RISK

Based on the given definitions we will now try to structure the various wildfire research activities in order to assess their contributions to wildfire risk. We hope that this helps to elucidate the use of wildfire risk terminology. Furthermore, we are convinced that wildfire risk analysis helps to integrate the three main research topics, wildfire effects, behavior and occurrence and thus stimulates interdisciplinary approaches in wildfire research.

Following a top-down approach, wildfire risk is subdivided into probability of occurrence and outcome. Based on their influence, the three wildfire research topics can be associated to them as shown in Figure 3.

Probability of Occurrence

According to the so-called 'fire fundamentals triangle' (Pyne et al. 1996, p. 7), the occurrence probability depends on the availability of fuel, the presence of a 'heat source' for the ignition and oxygen. We assume that the presence of oxygen is not critical in the context of wildfire risk analysis and therefore concentrate on the former two legs of the fire triangle. It is important to

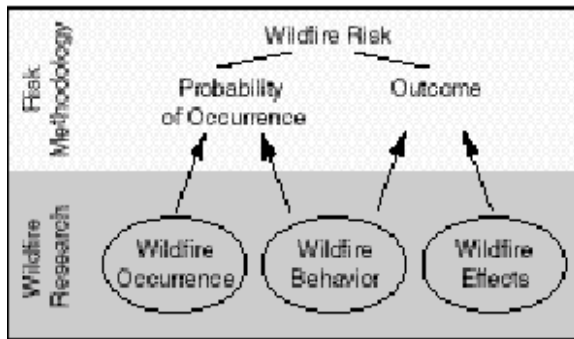


Figure 3. Risk Methodology and Wildfire Research.

note that a fire only occurs when all factors are present. The presence and state of fuel can be seen as an essential precondition, while the heat source is the immediate cause for a wildfire. Figure 4 shows which wildfire aspects are determining the risk relevant factors 'ignition causes' and 'preconditions.'

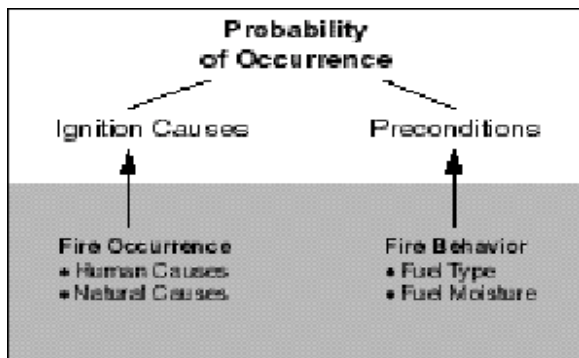


Figure 4. Factors influencing Probability of Occurrence.

Ignition Causes

There is no fire without a cause, even if we don't know it. Most of the fires are caused by human activities and that is where most of the research emphasis is laid on.

- **Human Causes:** As it is very difficult to model spatio-temporal patterns of human activities, a large number of indirect indicators are studied, e.g. spatial distributions of camp resorts, garbage dump sites, road networks and settlements or temporal patterns like weekday, national celebration days, etc. Research methods can be classified according to their dimensions: temporal, spatial or spatio-temporal. Examples can be found by Alcázar et al. (1998), Langhart et al. (1998), Martell et al. (1987) and Chuvieco et al. (1998).

- **Natural Causes:** Depending on the regional patterns, lightning can be quite an important cause for wildfires. E.g., in the pacific regions of the USA 31% of wildfires are caused by lightning (U. S. Forest Service, Cooperative Fire Program, in Pyne et al. 1996, p.390). This number roughly corresponds to the results of a study in southeastern Switzerland where 26% of the recorded fires are caused by lightning (Langhart et al. 1998). However, in general, natural causes don't seem to be of great interest for the wildfire research community.

Preconditions

The fuel complex research can be classified in at least two main fields: The classification of fuels and fuel moisture estimation.

- **Fuel Classification:** This includes studies ranging from discriminating between fuel and non-burnable land cover to sophisticated fuel structure analysis. E.g., even if there is fuel at some location, the structure of the particles and overall arrangement has to be favorable in order to enable a spark to become a self-sustaining wildfire (Silva 1998). Methods that deliver answers for these aspects are mainly field investigations or classifications of aerial or satellite imagery.
- **Fuel Moisture:** Another important parameter that influences the probability is the fuel moisture content. As it has a high temporal variability, it is studied intensely in remote sensing. Examples are the determination of NDVI and surface temperature (Prosper-Laget et al. 1998, Aguado et al. 1998, Deshayes et al. 1998). Nevertheless, interpolation and modeling based on point measurements in the field (Dimitrakopoulos and Mateeva 1998) are still widely used as the costs for data capturing and processing is relatively low compared to remote sensing methods. Furthermore, a lot of experience has been collected in the operational use of systems like FWI (Van Wagner 1987) or the Keetch-Byram drought index (Keetch and Byram 1968), which is very useful for this purpose.

It is important to reconsider that any method studying the aforementioned aspects should deliver a probability as result if it should be used in wildfire risk analysis. The probability of occurrence is then:

$$P_j = P_{\text{ignition}} \cdot P_{\text{precondition}} \quad (3)$$

P_{ignition} expresses the probability that any cause starts the wildfire and $P_{\text{precondition}}$ is the probability that the

Aspect	Methods	Examples
Preconditions <ul style="list-style-type: none"> • Presence of Fuel • Fuel Type • Fuel Moisture 	<ul style="list-style-type: none"> • Field Investigations • Aerial / Satellite Imagery • Field Measurements 	<ul style="list-style-type: none"> • Vegetation classification • NDVI, T_g • FFMCI, DMC, etc.
Ignition Causes <ul style="list-style-type: none"> • Human • Natural 	<ul style="list-style-type: none"> • Statistical Analysis 	<ul style="list-style-type: none"> • Logistic Regression

Table 1. Aspects of Wildfire Occurrence Probability.

fuel complex and fuel moisture allow the ignition of a fire. The product of both probabilities assures that if one of each is zero, the occurrence probability is zero too.

Outcome

As defined in equation 2, the extent of the outcome is determined by a weighted sum of the impacts of each object. This method allows to consider the fact that the outcome is not only a function of the burned area but rather dependent on particular high valuables, like buildings, etc. This is especially true for the urban wildland interface (Alexandrian 1997) where the value of the burned timber is nearly negligible compared to e.g. some expensive and luxurious residences.

For the impact probability, the most important factors are the fire behavior and its antagonist suppression (see figure 5). Fire behavior denotes in this context all parameters that influence the spreading of the fire. In the context of the impact on an object, fire behavior covers all aspects that might have a physical effect on an object. The impact is then a function of the susceptibility and the value assigned to the object.

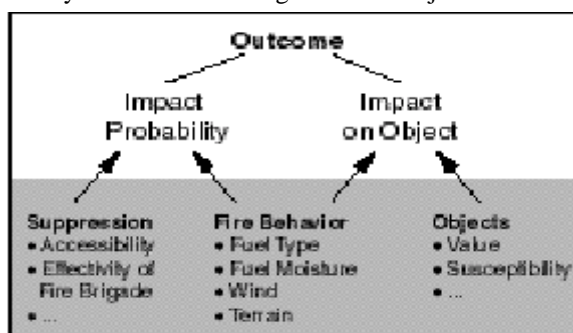


Figure 5. Aspects influencing the Outcome.

Impact Probability

Two opponents are found relevant: fire behavior and suppression.

- **Suppression:** A practical aspect that is worth to be studied is the accessibility. For every endangered object, the probability of being reached can be determined in relation to its accessibility, which has become a standard GIS-functionality in the meantime. Thus, for an entire region of interest the overall performance of the fire fighting organization can be assessed and integrated into the risk analysis. Bachmann (1996) proposes an exponential function that converts the travel time from the fire station to a specific object into a probability. The problematic point is the validation of such a function.
- **Fire Behavior:** The fire behavior describes the physical expression of the combustion process, e.g. heat release, reaction intensity, etc. In the context of determining the impact probability of an object, we are especially interested in studies that express either the rate of spread (Viegas et al. 1998) or the ease of suppression. In this domain, we find a lot of research under the label of 'fire hazard.' Typically, these studies concentrate on special fuel complex arrangements that lead to extreme fire behavior like high rates of spread, crowning (Allgöwer et al. 1998, Grishin 1998, Scott 1998), spotting, etc. Other studies concentrate on relation of specific meteorological conditions to extreme fire behavior (Bovio and Gamia 1998).

Impact on Objects

This is the core research topic of wildfire effects that tries to describe and model the impacts on a variety of

Aspect	Methods	Examples
Suppression <ul style="list-style-type: none"> • Effectivity of Fire Brigade • Accessibility 	<ul style="list-style-type: none"> • Analysis by Experts • Network Analysis 	<ul style="list-style-type: none"> • Water Catchments • Accessibility
Fire Behavior <ul style="list-style-type: none"> • Fuel • Wind • Terrain 	<ul style="list-style-type: none"> • Fire Behavior Models • Fire Spread Models 	<ul style="list-style-type: none"> • Heat Release, Intensity • Spread Rate • Crowning
Objects <ul style="list-style-type: none"> • Values • Susceptibility 	<ul style="list-style-type: none"> • Assessment by Experts • Interview (non market values) 	<ul style="list-style-type: none"> • Tax, Opportunity Cost • Tree Mortality

Table 2. Aspects of Wildfire Outcomes.

affected objects, e.g. tree mortality (Ryan 1998), erosion potential (Marxer et al. 1998), structure ignition (Cohen et al. 1991), etc. This is the susceptibility of the object, which is a function of the local fire behavior and the properties of the object itself. On the other side, we have the value of the object. In order to be used in the wildfire risk analysis it is of great importance that impacts are converted into monetary terms, as only in this form the various object categories can be compared with each other. It is clear that this is very difficult in some cases like erosion potential or destruction of a natural reservation. But, it is encouraging to see that there is an increasing research interest of economists to value 'nonmarket objects' (Cabán 1998). For other objects, it seems quite straightforward to estimate the damage, e.g. based on assurance valuations.

CONCLUSION AND OUTLOOK

Conclusion

We hope that the given examples of structuring wildfire research topics with respect to quantitative risk analysis help introducing the proposed wildfire risk terminology. Additionally, this integrative synopsis is expected to stimulate interdisciplinary research. In the operational use it can be useful for fire managers to see, how all the different aspects of wildfires can be put together to construct a more comprehensive understanding of this phenomenon.

It is clear, that setting up a terminology is only half the work. The other half is to show how it can be

applied. This is actually, what we are working at now.

Outlook

The presented terminology is part of a GIS-based framework that allows the analysis of the spatial distribution of wildfire risk (Bachmann and Allgöwer 1998, Schöning et al. 1997). The key elements are scenarios, 'situations' and 'objects' (see figure 6). Scenarios and objects have been already described in this paper. Situations are an additional feature that is used to comprise and define the state of all risk relevant parameters like weather, fuel or weekday, e.g. no rain since three weeks, high temperature combined with strong winds from the south and national celebration day. The concept of situations is very useful for grouping several scenarios together. This is necessary because there exists theoretically an infinite num-

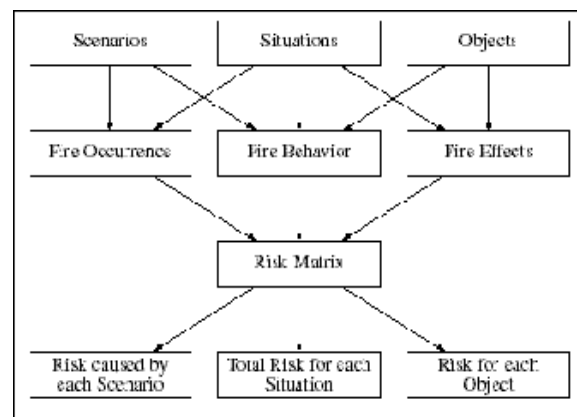


Figure 6. Framework for Wildfire Risk Analysis.

ber of locations in a given area of interest, which can serve as a starting point of a wildfire. Therefore, some spatial discretization (usually rasterizing) has to be applied, in order to get a finite number of scenarios. This set of scenarios is assumed to depend on the same state of all risk relevant parameters.

Using the methods of *fire occurrence* research, a probability must be assigned for each scenario to occur in the considered time span (i.e. the probability of ignition for each location in the study area, given a situation). The probability is then determined for each object to be affected by a given scenario. This is accom-

plished using appropriate *fire behavior models*. Finally, given a scenario, the amount of damage that each object will suffer must be estimated. This is the issue of *fire effects* research. For the actual risk analysis, these parameters are combined in a *risk matrix*, which depicts the relations between all scenarios and all objects for a given situation. The matrix permits the calculation of risk characteristics pertaining to scenarios, objects and the situation as a whole. A possible result could be e.g. a map like the following (see figure 7), showing the expected damage for both the scenarios and the objects, which are in this case buildings.

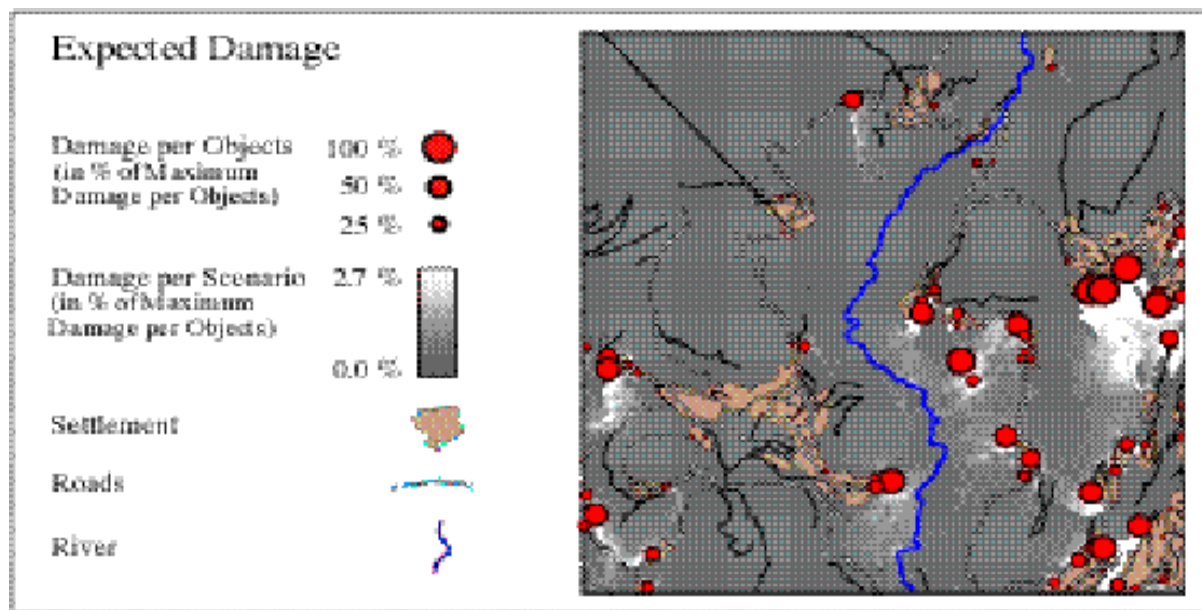


Figure 7. Example of Expected Damage for both Objects and Scenarios.

ACKNOWLEDGEMENTS

This work is funded by the Swiss National Science Foundation (Project-Nr. 21-50842.97) and by the Ministry for Education and Science (EC-Project INFLAME Nr. ENV4-CT98-0700, BBW Nr. 97.0182-2).

REFERENCES

Aguado, I., Chuvieco, E., Camarasa, A., Martín, P. and Camia, A. (1998). Estimation of meteorological fire danger indices from multitemporal series of NOAA-AVHRR Data. In: *Proceedings of the III International Conference on Forest Fire Research, 14th Conference on Fire and Forest Meteorology*. Coimbra, Portugal, Vol.1, pp. 1131-1147.

Alcázar, J., Garcia, P. V., Grauet, M., Pemán, J., Fernández, Á. (1998). Human risk and fire danger estimation through multicriteria evaluation methods for forest fire prevention in Barcelona, Spain. In: *Proceedings of the III International Conference on Forest Fire Research, 14th Conference on Fire and Forest Meteorology*. Coimbra, Portugal, Vol.2, pp. 2379 – 2387.

Alexandrian, D. (1996). A new method of fire danger mapping in the forest urban interface. In: *Proceedings of the workshop on wildfire management*. Athens, Greece.

Allen, F. R. (1992). *The management of risk to society from potential accidents*. Essex, UK.

- Allgöwer, B., Harvey, St. and Rügsegger, M. (1998). Fuel Models for Switzerland: Description, spatial pattern, index for torching and crowning. In: *Proceedings of the III International Conference on Forest Fire Research, 14th Conference on Fire and Forest Meteorology*. Coimbra, Portugal. Vol.2, pp. 2605-2620.
- Bachmann, A. (1996). GIS-Analysen für ein Waldbrandmanagementsystem. In: *Tagungsband zum Symposium der 176. Jahresversammlung der SANW. Geoprocessing Series*. Zurich, Switzerland. Vol.31.
- Bachmann, A. and Allgöwer, B. (1998). A Framework for Wildfire Risk Analysis. In: *Proceedings of the III International Conference on Forest Fire Research, 14th Conference on Fire and Forest Meteorology*. Coimbra, Portugal. Vol.2, pp. 2177-2190.
- Bärtsch, A. (1998). GIS-Analysis for the concept of a fire management plan in Swiss National Park. MSc-Thesis. Zurich, Switzerland.
- Bovio, G. and Camia, A. (1998). An analysis of large fires danger conditions in Europe. In: *Proceedings of the III International Conference on Forest Fire Research, 14th Conference on Fire and Forest Meteorology*. Coimbra, Portugal. Vol.1, pp. 975-994.
- Cabán, A. G. (1998). The importance of nonmarket values in land and fire management planning. In: *Proceedings of the III International Conference on Forest Fire Research, 14th Conference on Fire and Forest Meteorology*. Coimbra, Portugal. Vol.2, pp. 2191-2208.
- CCFFM. (1987). Õ Poulin et al. (1987).
- Chuvieco, E., Salas, J., Barredo, J. I., Carvacho, L., Karteris, M. and Koutsias, N. (1998). Global patterns of large fires occurrence on the European mediterranean basis: a G.I.S. analysis. In: *Proceedings of the III International Conference on Forest Fire Research, 14th Conference on Fire and Forest Meteorology*. Coimbra, Portugal. Vol.1, pp. 2447-2462.
- Cohen, J. D., Chase, R. A., LeVan, S. L. and Trna, H. C. (1991). A model for assessing potential structure ignitions in the wildland/urban interface. In: *Proceedings of the 11th Conference on Fire and Forest Meteorology*, Missoula, Montana, USA. p. 50-57.
- Deshayes, M., Chuvieco, E., Cocero, D., Karteris, M., Koutsias, N., and Stach, N. (1998). Evaluation of different NOAA-AVHRR derived indices for fuel moisture content estimation: interest for short term fire risk assessment. In: *Proceedings of the III International Conference on Forest Fire Research, 14th Conference on Fire and Forest Meteorology*. Coimbra, Portugal. Vol.1, pp. 1149-1167.
- Dimitrakopoulos A. P. and Mateeva V. (1998). Effect of moisture content on the ignitability of mediterranean species. In: *Proceedings of the III International Conference on Forest Fire Research, 14th Conference on Fire and Forest Meteorology*. Coimbra, Portugal. Vol.1, pp. 455-466.
- FAO. (1986). *Wildfire management terminology. Terminologie de la lutte contre les incendies de forêt. Terminología del control de incendios en tierras incultas*. Forest Resources Development Branch. Food and Agricultural Organization of the United Nations, Rome.
- Gheorghe, A. and Nicolet-Monnier. (1995). *Integrated Regional Risk Assessment. Continuous and Non-Point Source Emissions: Air, Water, Soil*. Vol.1. Dordrecht.
- Grishin, A. M. (1998). Mathematical and physical modeling of the crown forest fire initiation and spread. In: *Proceedings of the III International Conference on Forest Fire Research, 14th Conference on Fire and Forest Meteorology*. Coimbra, Portugal. Vol.1, pp. 433-434.
- Hall, J. R. (1992). *Fire Risk Analysis, Fire Hazard and Fire Risk Assessment*, pp. 21-10 - 21-18, Philadelphia, PA.
- Jones, D. A. (1992). Nomenclature of hazard and risk assessment in the process industries. Institution of Chemical Engineers. Rugby, Warwickshire, UK.
- Keetch, J. J. and Byram, G. M. (1968). A drought index for forest fire control. Research Paper SE-38. USDA Forest Service. Asheville, North Carolina, USA.
- Kolmogorov, A. N. (1933). *Grundbegriffe der Wahrscheinlichkeitsrechnung*. Berlin, Germany.
- Kumamoto H. and Henley E. J. (1996). *Probabilistic risk assessment and management for engineers and scientists*. 2nd Edition, IEEE New York, USA.
- Langhart R., Bachmann A. and Allgöwer B. (1998). Temporal and spatial patterns of wildfire occurrence (Canton of Grisons, Switzerland). In: *Proceedings of the III International Conference on Forest Fire*

Research, 14th Conference on Fire and Forest Meteorology. Coimbra, Portugal. Vol.2, pp. 2279 – 2292.

Martell D. L., Otukol S. and Stocks B. J. (1987). A logistic model for predictiong daily people-caused forest fire occurrence in Ontario. In: *Canadian Journal of Forestry Research*. 17:394-401.

Marxer P., Conedera M. and Schaub D. (1998). Postfire runoff and soil erosion in sweet chgestnut forests in south switzerland. In: *Proceedings of the III International Conference on Forest Fire Research, 14th Conference on Fire and Forest Meteorology*. Coimbra, Portugal. Vol.2, pp. 1317–1331.

Merz, H. A., Schneider, Th. and Bohnenblust, H. (1995). Bewertung von technischen Risiken. Beiträge zur Strukturierung und zum Stand der Kenntnisse. Modelle zur Bewertung von Todesfallrisiken. Polyprojekt Risiko und Sicherheit, Dokumente Nr. 3. Zürich, Switzerland.

MOF. (1997). Õ Ministry of Forests (1997).

Ministry of Forests. (1997): Glossary of forestry terms. Province of British Columbia, Canada <http://www.for.gov.bc.ca/pab/publctns/glossary/glossary.htm>.

Poulin, S., Merrill, D. F. and Alexander, M. E. (1987). Glossary of Forest Fire Management Terms. *Canadian Committee on Forest Fire Management, National Research Council of Canada*. (ed.) D.F. Merrill and M.E. Alexander. Ottawa: The Council, 4th ed., pp.91.

Prosper-Laget, V., Douguédroit, A. and Guinot, J-P. (1998). A Satellite Index of Risk of Forest Fire Occurrence in Summer in the Mediterranean Area. *The International Journal of Wildland Fire*, 8(4):173-182.

Pyne, Stephen J., Andrews, Patricia L., Laven, Richard D. (1996). *Introduction to wildland fire*. John Wiley & Sons, New York.

Ryan, K. C. (1998). Analysis of the relative value of morphological variables in predicting fire-caused tree mortality. In: *Proceedings of the III International Conference on Forest Fire Research, 14th Conference on Fire and Forest Meteorology*. Coimbra, Portugal. Vol.2, pp. 1511–1526.

Schöning, R. Bachmann, A. and Allgöwer, B. (1997). GIS-based framewrok for wildfire risk assessment. Final report for MINERVE 2, Zurich, Switzerland.

Scott, J. H. (1998). Sensitivity analysis of a method for assessing crown fire hazard in the northern rocky mountains, USA. In: *Proceedings of the III International Conference on Forest Fire Research, 14th Conference on Fire and Forest Meteorology*. Coimbra, Portugal. Vol.2, pp. 2517–2532.

Seiffert, Helmut. (1997). Einführung in die Wissenschaftstheorie, Vol. 4. München.

Silva y, F. R. (1998). Local evaluation of the forest fires risk through danger indices, application to the forest regions of Andalusia. In: *Proceedings of the III International Conference on Forest Fire Research, 14th Conference on Fire and Forest Meteorology*. Coimbra, Portugal. Vol.1, pp. 1071–1084.

Van Wagner, C. E. (1987). *Development and Structure of the Canadian Forest Fire Weather Index System*. In: *Forestry Technical Report 35*, Canadian Forestry Service.

Viegas D. X., Ribeiro P. R. and Cruz M. G. (1998). Characterisation fo the combustibility of forest fuels. In: *Proceedings of the III International Conference on Forest Fire Research, 14th Conference on Fire and Forest Meteorology*. Coimbra, Portugal. Vol.1, pp. 467-482.

Webster's College Dictionary. (1992). Random House, New York.